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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Department of the Navy

FREE-SPINNING-TUNNEL INVESTIGATION OF A $\frac{1}{24}$ - SCALE MODEL OF THE GRUMMAN AF-2S, -2W AIRPLANE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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FREE-SPINNING-TUNNEL INVESTIGATION OF A $\frac{1}{24}$-SCALE MODEL OF THE GRUMMAN AF-2S, -2W AIRPLANE

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SUMMARY

An investigation of the spin and recovery characteristics of a $\frac{1}{24}$-scale model of the Grumman AF-2S, -2W airplane was conducted in the Langley 20-foot free-spinning tunnel. The effects of controls on the erect and inverted spin and recovery characteristics for a range of possible loadings of the airplane were determined. The effect of a revised-tail installation (small dual fins added to the stabilizer of the original tail and the vertical-tail height of the original tail increased) and the effect of various ventral-fin and antispin-fillet installations were determined. The investigation also included spin-recovery parachute tests.

The results of the tests indicated that the AF-2S, -2W airplane will have unsatisfactory recovery characteristics from fully developed erect spins with either the original or the revised tail installed. The addition of either a large ventral fin (approx. 12 in. deep, full-scale) or large antispin fillets (6.2 ft long and 3.1 ft spanwise, full-scale) to the revised-tail configuration led to satisfactory spin-recovery characteristics by normal use of controls (full rudder reversal followed approximately 1/2 turn later by movement of the elevator down). Recoveries from inverted spins of the airplane with the original or revised tail were indicated to be satisfactory by neutralization of all controls. On the basis of model tests, it appears that a 12-foot flat-type spin-recovery tail parachute (drag coefficient of 0.67) should be effective for recoveries from demonstration spins.

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INTRODUCTION

In accordance with the request of the Bureau of Aeronautics, Department of the Navy, tests were performed in the Langley 20-foot free-spinning tunnel to determine the spin and recovery characteristics of a $\frac{1}{24}$-scale model of the Grumman AF-2S, -2W airplane. The AF-2S is the basic airplane design and the airplane designation changes to AF-2W when a large bulbous radome is installed beneath the fuselage.

The AF-2S model was investigated in its basic flight loading for both inverted and erect spins. Tests were also conducted with the AF-2S model loaded to simulate the catapult condition. The AF-2W version of the model was investigated in the maximum overload condition and in the basic flight loading with wing fuel removed. The effect of revising the tail to correspond to the alterations made to the airplane by the Grumman Aircraft Engineering Corp. as spin-tunnel tests were in progress was determined. Tests were performed to determine the size of parachute required for emergency spin recovery, and, in addition, tail modifications were tested on the model in an attempt to improve spin-recovery characteristics.

SYMBOLS

b	wing span, feet
S	wing area, square feet
c	wing or elevator chord at any station along the span, feet
$\bar{c}$	mean aerodynamic chord, feet
$\frac{x}{\bar{c}}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord.
$\frac{z}{\bar{c}}$	ratio of distance between center of gravity and fuselage reference line to mean aerodynamic chord (positive when center of gravity is below line)
m	mass of airplane, slugs
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-feet^2

$\frac{I_X - I_Y}{mb^2}$	inertia yawing-moment parameter
$\frac{I_Y - I_Z}{mb^2}$	inertia rolling-moment parameter
$\frac{I_Z - I_X}{mb^2}$	inertia pitching-moment parameter
ρ	air density, slug per cubic foot
μ	relative density of airplane $\left(\frac{m}{\rho Sb}\right)$
α	angle between fuselage reference line and vertical (approx. equal to absolute value of angle of attack at plane of symmetry), degrees
ϕ	angle between span axis and horizontal, degrees
V	full-scale true rate of descent, feet per second
Ω	full-scale angular velocity about spin axis, revolutions per second
σ	helix angle, angle between flight path and vertical, degrees (for the tests of this model, the average absolute value of the helix angle was approximately 4°)
β	approximate angle of sideslip at center of gravity, degrees (sideslip is inward when inner wing is down by an amount greater than the helix angle)
TDPF	tail-damping power factor (see reference 1)
TDR	tail-damping ratio (see reference 1)

APPARATUS AND METHODS

Model

The $\frac{1}{24}$- scale model of the Grumman AF-2S, -2W airplane was furnished by the Bureau of Aeronautics, Department of the Navy, and was checked for dimensional accuracy and prepared for testing by the Langley Laboratory. The dimensional characteristics of the model converted to corresponding full-scale values are given in table I. A three-view drawing of the AF-2S version of the model as received at Langley is shown with external wing tanks installed in figure 1.

During the course of testing, information was received from the Grumman Aircraft Corp. that small dual fins, roughly triangular in shape, were to be added to the airplane and, accordingly, these fins were installed on the model. These fins are shown in figure 2 and were placed on the model at either 0° or 4° offset to the left. Subsequent to the receipt of the preceding information, the tail design of the AF-2S, -2W airplane was again altered in that the vertical-tail height was increased, the triangular dual fins were replaced by rectangular dual fins (called finettes) placed on the stabilizer at 0° offset, and a ventral fin $1\frac{1}{2}$ inches deep (full-scale) was added. The rudder and aileron deflections were also altered, but the alteration to the aileron deflection was so slight (reduced from 20° up to 19° up) that only the rudder throw was changed on the model. The tail of the model was modified to incorporate the preceding changes except for the small ventral-fin installation and this final version of the tail as tested on the model is shown as figure 3. The $1\frac{1}{2}$-inch, full-scale, ventral fin was not incorporated into the final version of the tail because test data obtained prior to receipt of information on the tail revisions adequately indicated the effect of such a change. Ventral-fin and antispin-fillet modifications investigated on the model are shown in figure 4.

The model could be converted from the AF-2S to the AF-2W by the installation of a radome under the fuselage. A three-view drawing of the AF-2W version of the model with the original tail installed and with external wing tanks attached is shown in figure 5. The AF-2S, -2W has a fixed slot in the leading edge of the wing. This slot is illustrated in figures 1 and 5 and in the photographs of the model with the original tail installed, shown in figures 6 and 7 for the AF-2S and AF-2W versions, respectively.

Upper-surface spoilers, called flaperons and flaperettes, are used in conjunction with the ailerons to provide lateral control of the airplane. The size and position of the flaperons and flaperettes investigated on the model are shown in figure 8. The deflection of the lateral controls plotted against stick travel is shown in figure 9. As is indicated in figure 8, the flaperettes are narrow-chord spoilers and are pivoted near the trailing edge of the larger-chord flaperons. As the stick travels laterally, the flaperette is deflected first and reaches its full deflection after 2/7 of the stick's full lateral deflection, and after the flaperette is fully deflected the flaperon begins to deflect, reaching its full deflection after 4/7 of the stick's full lateral deflection.

The model was ballasted with lead weights to obtain dynamic similarity to the airplane at an altitude of 25,000 feet (ρ = 0.001065 slug per cubic foot) rather than the usual 15,000 feet, because of the relatively heavy construction of the model.

The propeller was not simulated on the model for these tests inasmuch as unpublished data have indicated little effect of a windmilling propeller on the spin characteristics of conventional designs.

Wind Tunnel and Testing Technique

The model tests were performed in the Langley 20-foot free-spinning tunnel the operation of which is generally similar to the Langley 15-foot free-spinning tunnel which is described in reference 2, except that the model launching technique has been changed. With the controls set in the desired position, the model is now launched by hand with rotation into the vertically rising air stream. After a number of turns in the established spin, recovery is attempted by moving one or more controls by means of a remote-control mechanism. After recovery, the model dives into a safety net. A photograph of the model during a spin is shown in figure 10.

The data presented were determined by methods described in reference 2 and have been converted to corresponding full-scale values. The turns for recovery are measured from the time the controls are moved, or the parachute is opened, to the time the spin rotation ceases and the model dives into the net. For the spins which had a rate of descent in excess of that which can readily be attained in the tunnel, the rate of descent was recorded as greater than the velocity at the time the model hit the safety net, for example, >369. For these tests, the recovery was attempted before the model reached its final steeper attitude and while the model was still descending in the tunnel. Such results are conservative, that is, recoveries will not be as fast as when the model is in the final steeper attitude. For recovery attempts in which the model struck the safety net while it was still in a spin, the recovery was recorded as greater than the number of turns from the time the controls were moved to the time the model struck the net, as >4. A >4-turn recovery does not necessarily indicate an improvement over a >7-turn recovery. When the model failed to recover within 10 turns, the recovery was recorded as ∞. For recovery attempts in which the model recovered without control movement with the controls with the spin, the result was recorded as "No spin."

Spin-tunnel tests are usually made to determine the spin and recovery characteristics of the model at the normal spinning control configuration (elevator full-up, ailerons neutral, and rudder full with the spin) and at various other aileron-elevator control combinations, including zero and maximum deflections. Recovery is attempted either by rapid full rudder reversal alone or by rapid full reversal of both rudder and elevator. Tests are also performed to evaluate the possible adverse effects on recovery of small control deviations from the normal control configuration for spinning. For this type of test the ailerons are set at one-third of the full deflection in the direction of the slower recoveries and the elevator is set at full-up or two-thirds of its full-up deflection, whichever will cause slower recoveries. Recovery is attempted either by rapid rudder reversal alone from full with the spin to two-thirds against the spin or by simultaneous rapid rudder reversal from full with the spin to two-thirds against the spin and movement of the elevator down. This control configuration and movement are referred to as the "criterion spin." For the present tests, the criterion-spin control setting was lateral controls 1/3 against the spin, elevator 2/3 up and rudder full with the spin; the control movement for recovery was simultaneous reversal of rudder to 2/3 against the spin and movement of the elevator to 2/3 full down. Recovery characteristics of the model are considered satisfactory if recovery from this criterion spin requires $2\frac{1}{4}$ turns or less. This value has been selected on the basis of full-scale airplane spin-recovery data that are available for comparison with corresponding model test results.

For the spin-recovery parachute tests, the minimum size parachute required to effect recovery from the criterion spin within $2\frac{1}{4}$ turns after the packed parachute was opened was selected as the parachute required for satisfactory termination of the spin. The towline length used on the spin-recovery parachutes was selected on the basis of the data presented in reference 3. The parachute towline was attached to the model at the rear of the fuselage below the horizontal tail. The folded parachute was placed on the inboard side of the fuselage (right side in a right spin) just below the horizontal tail and did not alter the steady spin before the parachute was opened. For the current tests, the controls were not moved during recovery so that recovery was entirely due to the effect of opening the parachute. Flat-type nylon parachutes having a drag coefficient of approximately 0.67 (based upon the canopy area measured with the parachute laid out flat) were used for the spin-recovery parachute tests. The parachute was opened for recovery attempts by actuating the remote-control mechanism, and the parachute was blown clear of the model by the action of the air stream. It is recommended that the full-scale parachute installation be provided with a positive means of ejection, and that the packed parachute be placed within the airplane structure if possible.

PRECISION

The spin results presented herein are believed to be the true values given by the model within the following limits:

α, degrees	±1
ϕ, degrees	±1
V, percent	±5
Ω, percent	±2
Turns for recovery	±1/4 turn when obtained from motion-picture records; ±1/2 turn when obtained by visual estimate

The preceding limits may have been exceeded for certain spins in which it was difficult to control the model in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

Comparison between model and airplane spin results (reference 4) indicates that spin-tunnel results will satisfactorily predict full-scale recovery characteristics 90 percent of the time and that, for the remaining 10 percent, the model results will be of value in predicting some of the details of the full-scale spins and the relative effectiveness of the controls on the recovery characteristics. In general, when the model spun at an angle of attack less than 45°, the corresponding airplane spun at a lower angle of attack, and when the model spun at an angle of attack greater than 45°, the corresponding airplane spun at a steeper attitude. The comparison presented in reference 4 also indicated that generally the model's inner wing was tilted less downward and the altitude loss per revolution was less than that of the corresponding airplane. It was also indicated that the corresponding airplane generally would spin at a greater or lower rate of rotation than the model, depending on whether the tail-damping ratio was greater or less than 0.02, respectively.

Because it is impracticable to ballast the model exactly, and because of inadvertent damage to the model during tests, the measured weight and mass distribution of the model varied from the true scaled-down values within the following limits:

Weight, percent	0 to 1 high
Center-of-gravity location, percent $\bar{c}$	
Longitudinally	0 to 2 rearward
Laterally	0 to 2 right
Moments of inertia	
I_X, percent	1 high to 6 high
I_Y, percent	0 to 8 high
I_Z, percent	0 to 5 high

The accuracy of measuring the weight and mass distribution is believed to be within the following limits:

Weight, percent	±1
Center-of-gravity location, percent $\bar{c}$	±1
Moments of inertia, percent	±5

Controls were set with an accuracy of ±1°.

Test Conditions

The mass characteristics and inertia parameters for the airplane loadings investigated on the model are shown in table II. The inertia parameters for these loadings are plotted in figure 11. As discussed in reference 5, figure 11 can generally be used in predicting the relative effectiveness of the controls on the recovery characteristics of the model. It should be noted, however, that for the present model the slat installation would tend to diminish any favorable effect due to placing the ailerons against the spin for those loading conditions where ailerons against the spin should be beneficial (see references 5 and 6). Tests were performed for the model conditions listed in table III.

The maximum control deflections (measured perpendicular to the hinge line of the control surfaces) used in the tests were:

Rudder, degrees	
Original	32 right, 27 left
Revised	31 right, 24 left
Elevator, degrees	27 up, 22 down
Ailerons, degrees	20 up, 17 down
Flaperon, degrees	40 up
Flaperette, degrees relative to flaperon surface	90 up

Intermediate control deflections used were:

Rudder, 2/3 deflected, degrees	
Original	$21\frac{1}{3}$ right, 18 left
Revised	$21\frac{1}{3}$ right, 16 left
Elevator, 2/3 up, degrees	18
Elevator, 1/3 down, degrees	14
Lateral controls 1/3 deflected (corresponding to approx. 2.5 in. of lateral stick travel on the airplane)	
Ailerons, degrees	$6\frac{2}{3}$ up, $5\frac{2}{3}$ down
Flaperon, degrees	10
Flaperette, relative to flaperon, degrees	90

As previously mentioned, a plot showing the lateral stick travel against the deflections of the various lateral controls is shown as figure 9.

RESULTS AND DISCUSSION

The results of the spin tests of the model are presented in charts 1 to 7 and tables IV and V. The model data are presented in terms of the full-scale values for the airplanes at a test altitude of 25,000 feet. Based on spin-tunnel experience, it is felt that the current results are probably somewhat conservative as compared to corresponding results which would be obtained at an altitude of 15,000 feet. All tests were performed with the model in the clean condition (cockpit closed, flaps neutral, landing gear retracted).

The center of gravity of the airplane was displaced laterally from the plane of symmetry and the rudder deflections to the right and left were different and, although simulated on the model, the model's spin and recovery characteristics were generally quite similar to the right and to the left. Inasmuch as the rudder on the model did not extend below the horizontal tail, it appears that most of the rudder may have been shielded by the horizontal tail during the spin, and, therefore, the model was not sensitive to small variations in rudder setting. Apparently the lateral displacement of the center of gravity was not of sufficient magnitude to cause any appreciable difference in the results of right and left spins. On the basis of the model results it appears that power-off spins of the full-scale airplane should be similar to the right and to the left. The spin data presented in the charts and tables are arbitrarily presented in terms of right spins.

Original Tail

The results of the erect spin tests of the model with the original tail installed (fig. 1) are presented in charts 1 to 3.

AF-2S - basic loading and catapult condition.- As is shown in charts 1 and 2, the spin test results for the AF-2S model were generally similar for the basic loading and for the catapult conditions (loading points 1 and 2, respectively, in table II and fig. 11) except that ailerons with the spin had a favorable effect on recoveries for the basic loading, whereas recoveries attempted from the catapult condition by rudder reversal alone were affected adversely by placing the ailerons with the spin from elevator-up spins. Recoveries from elevator-neutral or down spins for the catapult conditions were indicated to be little affected by aileron position. Elevator full-up generally was indicated to be the most favorable elevator setting for recovery, and setting the elevator down before reversal of the rudder led to poor recoveries for all aileron settings.

In order to evaluate the possible adverse effects of small deviations from the normal control configuration for spinning, tests were run at the control configuration previously referred to as the criterion spin (for these tests, lateral controls deflected 1/3 against the spin and elevator set at 2/3 of its full-up deflection). The data presented in charts 1 and 2 indicate that recoveries from this spin were unsatisfactory either by reversal of rudder or by reversal of both rudder and elevator. On the basis of these test results the recovery characteristics of the model are considered unsatisfactory, and it appears that normal control manipulation for recovery (full rapid rudder reversal followed approximately 1/2 turn later by movement of the elevator down) may not satisfactorily terminate a fully developed spin on the airplane.

AF-2W overload condition.- The results of the spin tests of the AF-2W model (radome installed) for the overload gross weight loading (loading point 3 in table II and fig. 11) are presented in chart 3. This loading represents the AF-2W airplane in the take-off condition with the maximum amount of fuel. It should be noted that this loading is similar to that of the AF-2S in the catapult condition (compare loadings 2 and 3 in table II).

The results for this loading are similar to those obtained for the AF-2S model in the catapult condition (compare charts 2 and 3) and indicate that recoveries will be unsatisfactory either by rudder reversal alone or by simultaneous rudder and elevator reversal, as shown by recoveries obtained from the criterion spin. Inasmuch as the mass loadings of the AF-2S in the catapult condition and the AF-2W in the overload condition are similar and inasmuch as the spin and recovery characteristics are essentially the same, the aerodynamic effect of the radome on the spins is thus indicated to be slight. This effect is similar to that reported in reference 7 for a model of somewhat similar proportions.

Revised Tail and Tail Modifications

No offset in small dual vertical fins.- The results of brief tests conducted with small triangular dual fins installed on the stabilizer with 0° fin offset as shown in figure 2, a tail revision initially contemplated by Grumman, are presented in chart 4. Comparison of the data presented in charts 1 to 3 with the data presented in chart 4 indicates that there was little effect of installing the triangular dual fins. Brief tests conducted at the AF-2S basic loading condition with the rectangular finettes installed with 0° offset and the vertical-tail height increased (fig. 3), the final revised version of the tail, indicated that this tail configuration did not improve the spin-recovery characteristics. (See table V.)

In an attempt to improve the spin-recovery characteristics of the model to the extent necessary to make them satisfactory, several modifications were made to the tail. The tail installed on the model for these tests was the final revised tail (rectangular finettes and increased vertical-tail height, fig. 3). These tests were conducted at the two extremes in loadings of the airplane as regards the inertia yawing-moment parameter: the AF-2W overload condition $\left(\frac{I_X - I_Y}{mb^2} = 0\right)$ and the AF-2W basic loading condition less wing fuel $\left(\frac{I_X - I_Y}{mb^2} = -79 \times 10^{-4}\right)$, loadings 3 and 4 in table II, respectively. Inasmuch as the loadings possible on the two versions of the airplane (AF-2S or AF-2W) fall within this range of inertia yawing-moment parameters, it is felt that any modifications satisfactory for the two conditions investigated would be satisfactory for the intermediate conditions. (The AF-2W basic loading condition less wing fuel, loading number 4 in table III, was investigated after it had been determined that there was little aerodynamic effect of installing the radome. In order to expedite testing, the model was tested with the radome replaced by equivalent weight in the fuselage for this loading condition.) The results of the tail-modification tests are indicated in table V and charts 5 and 6.

For the AF-2W basic loading less wing fuel, a ventral fin 4 inches deep, full scale, (indicated by Grumman to be the maximum ventral fin depth permissible on the airplane) which extended from approximately the trailing edge of the wing to the trailing edge of the elevator did not improve the recovery characteristics (modification number 1 in table V and fig. 4). Increasing the ventral-fin depth to approximately 8.4 inches, full scale (modification number 2), was not sufficient to lead to satisfactory recovery characteristics (table V). Preliminary test information had indicated that when the opening between the wing and the slat was smaller than the required amount, this modification would be of sufficient size to enable satisfactory recovery characteristics. With the slot gap set to the correct amount, a ventral fin approximately 12 inches deep and 8.72 square feet in area (full scale), modification number 3, satisfactorily improved the spin-recovery characteristics for this loading condition, provided both rudder and elevator were reversed for recovery (table V).

Inasmuch as the large ventral fin necessary to obtain satisfactory spin recoveries cannot be tolerated on the airplane, antispin fillets were investigated on the model. As is shown in figure 4, the fillets were installed at the intersection of the horizontal tail and the fuselage and in the chord plane of the horizontal tail. As is indicated by the data presented in table V and chart 5, the minimum size fillet that provided satisfactory recoveries for the AF-2W basic loading condition less wing fuel $\left(\frac{I_X - I_Y}{mb^2} = -79 \times 10^{-4}\right)$ was one that measured 6.2 feet along the fuselage and 3.1 feet spanwise (full scale), modification 4 in figure 4, provided both rudder and elevator were reversed for recovery. Smaller antispin fillets, modifications 5 and 6, were found to be inadequate (see table V and fig. 4).

Tail-modification tests conducted at the other loading extreme, the AF-2W overload condition $\left(\frac{I_X - I_Y}{mb^2} = 0\right)$, indicated that the modifications found to be satisfactory at the AF-2W basic loading condition less wing fuel were still satisfactory at the AF-2W overload condition (table V and chart 6). Thus, on the basis of the results obtained for these two loadings, it appears that by the installation of either a ventral fin approximately 12 inches deep (full scale), modification 3, or antispin fillets 6.2 feet long and 3.1 feet spanwise (full scale), modification 4, spins obtained on the AF-2S, -2W airplane can be satisfactorily terminated by normal spin-recovery technique (full rapid reversal of the rudder followed approximately 1/2 turn later by movement of the elevator down). Although not specifically tested, raising the horizontal tail approximately 1.5 feet on the full-scale airplane would lead to a TDPF equivalent to that obtained by adding the largest ventral and thus might also provide satisfactory spin-recovery characteristics.

<u>Small dual fins offset</u>.- Brief tests were conducted with the dual triangular fins offset 4° to the left inasmuch as early information obtained from Grumman had indicated that such a tail revision was originally contemplated on the AF-2S, -2W design. The data obtained from these tests, not presented, indicated that offsetting the dual fins to the left had an adverse effect on recoveries from right spins inasmuch as the ventral-fin size required to enable satisfactory recoveries from spins with the fins offset was larger than the ventral-fin size required to enable satisfactory recoveries when the dual triangular fins were installed without offset. On the basis of these results, it appears that if the rectangular finettes incorporated into the final revised version of the tail (fig. 3) are installed with offset, the modifications found to lead to satisfactory recovery characteristics when the rectangular finettes were installed with no offset (modifications 3 and 4 in fig. 4) would no longer be adequate.

Inverted Spins

The results of the inverted-spin tests of the model in the basic loading with the original tail installed are presented in chart 7. Although not specifically tested, it is felt that the results of these inverted-spin tests are also applicable for the revised-tail installation. It should be noted that the order used for presenting the data for inverted spins is different from that used for erect spins. For inverted spins controls crossed for the established spin (right rudder pedal forward and stick to pilot's left for a spin to the pilot's right) is presented to the right of the chart and stick back is presented at the bottom. When the controls are crossed in the established spin, the ailerons aid the rolling motion; when the controls are together, the ailerons oppose the rolling motion. The angle ϕ in the chart is given as up or down relative to the ground.

The recovery characteristics from all inverted spins obtained were satisfactory by rudder reversal alone for all control configurations except for the configuration with the controls crossed and stick forward. The results indicate that merely neutralizing all controls will insure satisfactory recoveries from inverted spins.

Spin-Recovery Parachutes

The results of tests performed with spin-recovery parachutes attached to the tail of the model presented in table IV show that a 12-foot-diameter parachute (measured laid out flat) with a towline length of 30 feet appears to be necessary for satisfactory recovery from spins by parachute action alone. As previously indicated, the parachutes tested were of the flat-type variety having a drag coefficient of approximately 0.67. If a parachute with a different drag coefficient is used, a corresponding adjustment will be required in parachute size. Reference 8 indicates that conventional flat-type parachutes made of low-porosity materials are unstable and may seriously affect the stability of the airplane if the parachute is opened in normal flight to test its operation. It may be desirable, therefore, to use a stable parachute (reference 8) as an emergency spin-recovery device on the full-scale airplane.

The preceding tests were performed with the original tail installed on the model with the model ballasted to simulate the AF-2S basic loading condition (loading number 1 in table II). On the basis of the study presented in reference 9, the size parachute determined as being satisfactory for the condition tested would also be effective in terminating spins for any loading condition indicated as possible on the AF-2S, -2W airplane in table II with either the revised or modified tails investigated on the model.

Landing Condition

The landing condition was not investigated on this model inasmuch as current Navy specifications do not require airplanes to be spin-demonstrated in the landing condition. Analysis of full-scale and model tests on numerous designs to determine the effect of flaps and landing gear (reference 10) indicates that although the AF-2S, -2W airplane will probably recover satisfactorily from an incipient spin (1 turn or less) recoveries from fully developed spins in the landing configuration will probably be unsatisfactory. In order to avoid entering a fully developed spin, it is recommended that the flaps be neutralized and that recovery be attempted immediately upon inadvertently entering a spin in the landing condition.

CONCLUSIONS

Based on results of tests of a $\frac{1}{24}$-scale model of the Grumman AF-2S, -2W airplane, the following conclusions regarding the spin and recovery characteristics of the airplane at a test altitude of 25,000 feet are made:

1. The spin-recovery characteristics of the AF-2S, -2W airplane equipped with either the original tail or the revised tail will be unsatisfactory from fully developed erect spins.

2. Installing either a ventral fin (approx. 12 in. deep, full scale) below the horizontal tail or installing antispin fillets (6.2 ft long, 3.1 ft spanwise, full scale) at the juncture of the fuselage and the horizontal tail will lead to satisfactory recovery characteristics of the airplane with the revised tail by normal use of the controls (full rapid rudder reversal followed approx. 1/2 turn later by movement of the elevator down, ailerons maintained at neutral).

3. The radome installation will have no appreciable effect on the spin and recovery characteristics of the airplane.

4. Recoveries from inverted spins should be satisfactory by neutralization of all controls.

5. A 12-foot flat-type tail parachute (drag coefficient 0.67) with a towline of 30.0 feet will be satisfactory for emergency recoveries from demonstration spins.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF GRUMMAN AF-2S, -2W AIRPLANES

Length over all, ft (measured from intersection of nose and fuselage reference line to end of fuselage)	40.74
Wing:	
Span, ft	60
Area, sq ft	548.6
Section:	
Root (T.E. modified)	NACA 28018.75
Tip (T.E. modified)	NACA 23012
Incidence, deg	2
Dihedral, deg	5
Mean aerodynamic chord ($\bar{c}$), in.	115.07
Leading edge of mean aerodynamic chord rearward of leading edge of wing, in.	10.36
Ailerons:	
Area aft of hinge line (total), sq ft	33.4
Hinge line to trailing edge, in.	20.0
Span, percent b	35
Flaperons:	
Area aft of hinge line (total), sq ft	15.72
Span, percent b	20
Flapperettes:	
Area aft of hinge line (total), sq ft	2.75
Span, percent b	20
Slots:	
Length, percent b	33
Horizontal tail:	
Total area, sq ft	139.35
Span, ft	26.17
Elevator area aft of hinge line, sq ft	45.28
Distance from normal center of gravity to elevator hinge line, ft	23.65
Incidence, deg	2
Original vertical tail:	
Total area, sq ft	55.70
Total rudder area aft of hinge line, sq ft	17.36
Distance from normal center of gravity to rudder hinge line, ft	24.4
Tail-damping power factor	213×10^{-6}
Revised vertical tail:	
Total area, sq ft	65.4
Total rudder area aft of hinge line, sq ft	18.6
Distance from normal center of gravity to rudder hinge line, ft	24.4
Finette area, total, sq ft	27.5
Tail-damping power factor	522×10^{-6}

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TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADING CONDITIONS

OF GRUMMAN AF-2S, -2W AIRPLANE TESTED ON $\frac{1}{24}$-SCALE MODEL

[Full-scale values presented]

Airplane designation	Number	Loading	Weight (lb)	μ		Center-of-gravity location			Moments of inertia about center of gravity			Mass parameters		
				Sea level	25,000 feet	$x/\bar{c}$	$y/\bar{c}$	$z/\bar{c}$	I_X (slug-feet^2)	I_Y (slug-feet^2)	I_Z (slug-feet^2)	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
AF-2S	1	Basic flight, normal c.g.	19,200	7.6	17.0	0.256	-0.019	-0.072	33,527	44,120	74,787	-49×10^{-4}	-143×10^{-4}	192×10^{-4}
	2	Catapult condition (external wing tanks)	22,900	9.1	20.3	0.254	-0.016	-0.030	42,161	45,890	83,374	-14	-146	160
AF-2W	3	Maximum overload gross weight (external wing tanks)	21,800	8.7	19.4	0.277	-0.003	-0.039	45,343	45,485	87,458	0	-171	171
	4	Basic flight less wing fuel	18,777	7.4	16.6	0.263	-0.004	-0.068	27,940	44,597	69,273	-79	-117	196

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TABLE III.- CONDITIONS TESTED ON $\frac{1}{24}$ - SCALE MODEL OF

GRUMMAN AF-2S, -2W AIRPLANE

[Model loading numbers are those given in table II and fig. 11]

Loading	Type of spin	Model revisions	Data presented in	
			Chart	Table
1	Erect	None	1	[a]IV
	Inverted	None	7	
	Erect	Original tail with triangular dual fins installed	4	
	Erect	Revised tail	---	V
2	Erect	None	2	
	Erect	Original tail with triangular dual fins installed	4	
3	Erect	None	3	
	Erect	Original tail with triangular dual fins installed	4	
	Erect	Revised tail and ventral fin - modification number 2	---	V
	Erect	Revised tail and ventral fin - modification number 3	---	V
	Erect	Revised tail and antispin fillet - modification number 4	6	V
4	Erect	Revised tail and ventral fin - modification number 1	---	V
	Erect	Revised tail and ventral fin - modification number 2	---	V
	Erect	Revised tail and ventral fin - modification number 3	---	V
	Erect	Revised tail and antispin fillet - modification number 4	5	V
	Erect	Revised tail and antispin fillet - modification number 5	---	V
	Erect	Revised tail and antispin fillet - modification number 6	---	V

[a]Spin-recovery parachute data.

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TABLE IV.- TAIL PARACHUTE SPIN-RECOVERY DATA OBTAINED

WITH $\frac{1}{24}$-SCALE MODEL OF GRUMMAN AF-2S AIRPLANE

[Loading point 1 in table II and fig. 11, rudder full with the spin; model values converted to full-scale values; C_D of parachutes 0.67; right erect spins]

Parachute diameter (ft)	Towline length (ft)	Lateral controls	Elevator	Vertical rate of descent (fps)	Turns for recovery
11.4	30	$\frac{1}{3}$ against	$\frac{2}{3}$ up	249	1, $1\frac{1}{2}$, 2, 5
11.4	30	Full against	Neutral	222	3, $3\frac{1}{2}$, 9
12.0	30	$\frac{1}{3}$ against	$\frac{2}{3}$ up	249	$1\frac{1}{2}$, 2, 2
				Approx. 333	$\frac{1}{4}$, $\frac{3}{4}$, $\frac{3}{4}$
12.0	30	Full against	Neutral	222	$2\frac{1}{4}$, $2\frac{3}{4}$, 3

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[redacted]

TABLE V.- EFFECTIVENESS OF VARIOUS MODIFICATIONS TESTED ON $\frac{1}{24}$ -SCALE MODEL

OF GRUMMAN AF-2S, -2W AIRPLANE EQUIPPED WITH REVISED TAIL

[Model values are presented in terms of full-scale values. Steady-spin data presented for: rudder full with the spin, ailerons 1/3 against the spin, and elevator 2/3 up. Recovery attempted by simultaneous reversal of the rudder from full with to 2/3 against the spin and of the elevator from 2/3 up to 2/3 down]

Modification	$\frac{I_X - I_Y}{mb^2}$	Loading number	TDPF	V (ft/sec) (a)	α (deg) (a)	ϕ (deg) (a)	Ω (rev/sec)	Turns for recovery	Rating
None	-49×10^{-4}	1	522×10^{-6}	228	53	0	0.32	∞, ∞	Unsatisfactory
1	-79	4	551	232	57	0	0.32	∞, ∞	Unsatisfactory
2	0	3	574	304 340	32 45	3U 11D	0.34	$\frac{1}{2}$, $\frac{1}{2}$	Satisfactory
	-79	4	574	249 269	41 50	3U 4D	0.30	1, $3\frac{1}{2}$[b], ∞	Unsatisfactory
3	0	3	614	296 369	26 39	3U 11D	0.34	$\frac{1}{4}$, $\frac{1}{2}$	Satisfactory
	-79	4	614	263 296	34 46	1U 4D	0.31	$1\frac{3}{4}$, $1\frac{3}{4}$	Satisfactory
4	0	3	729	269 318	38	5D	0.34	$\frac{3}{4}$, 1	Satisfactory
	-79	4	729	272	39	1D	0.32	2, 2	Satisfactory
5	-79	4	729	242 269	42	1D	0.31	$3\frac{1}{4}$, ∞	Unsatisfactory
6	-79	4	639	242 256	40 45	2U 4D	0.32	∞, ∞	Unsatisfactory

[a]Average value or range of values given.
[b]Visual estimate.
U inner wing up.
D inner wing down.

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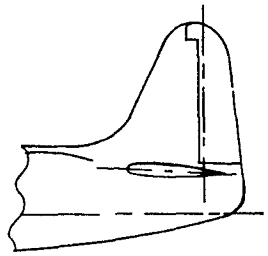
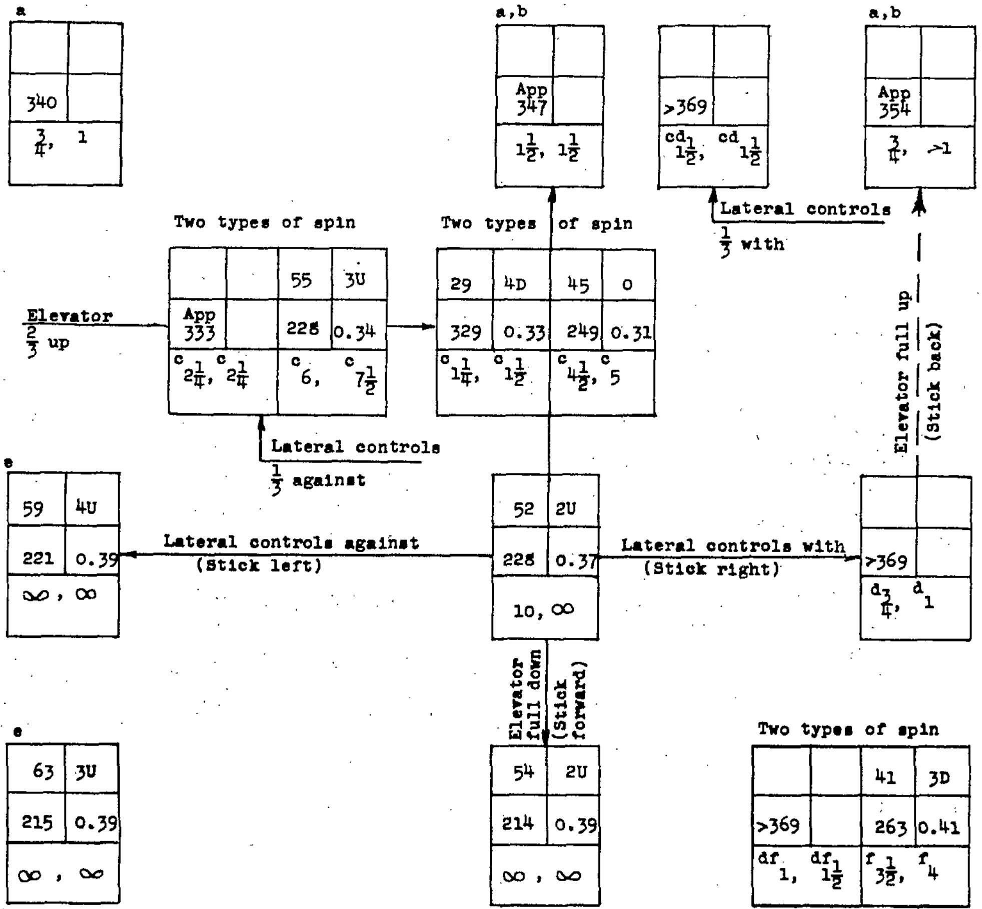
[redacted]

CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{24}$-SCALE MODEL OF GRUMMAN AF-2S AIRPLANE

EQUIPPED WITH ORIGINAL TAIL IN BASIC LOADING

[Loading point 1 in table II and fig. 11; flaps neutral; cockpit closed; landing gear retracted; slots open; recovery attempted by full rapid rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder full with spins); right erect spins]





[a] Wandering spin.
[b] Whipping spin.
[c] Recovery attempted by reversing rudder from with the spin to $\frac{2}{3}$ against the spin.
[d] Recovery attempted before model reached its final steeper attitude.
[e] Oscillatory in roll and yaw, average value given.
[f] Model goes into an inverted spin after recovery from erect spin.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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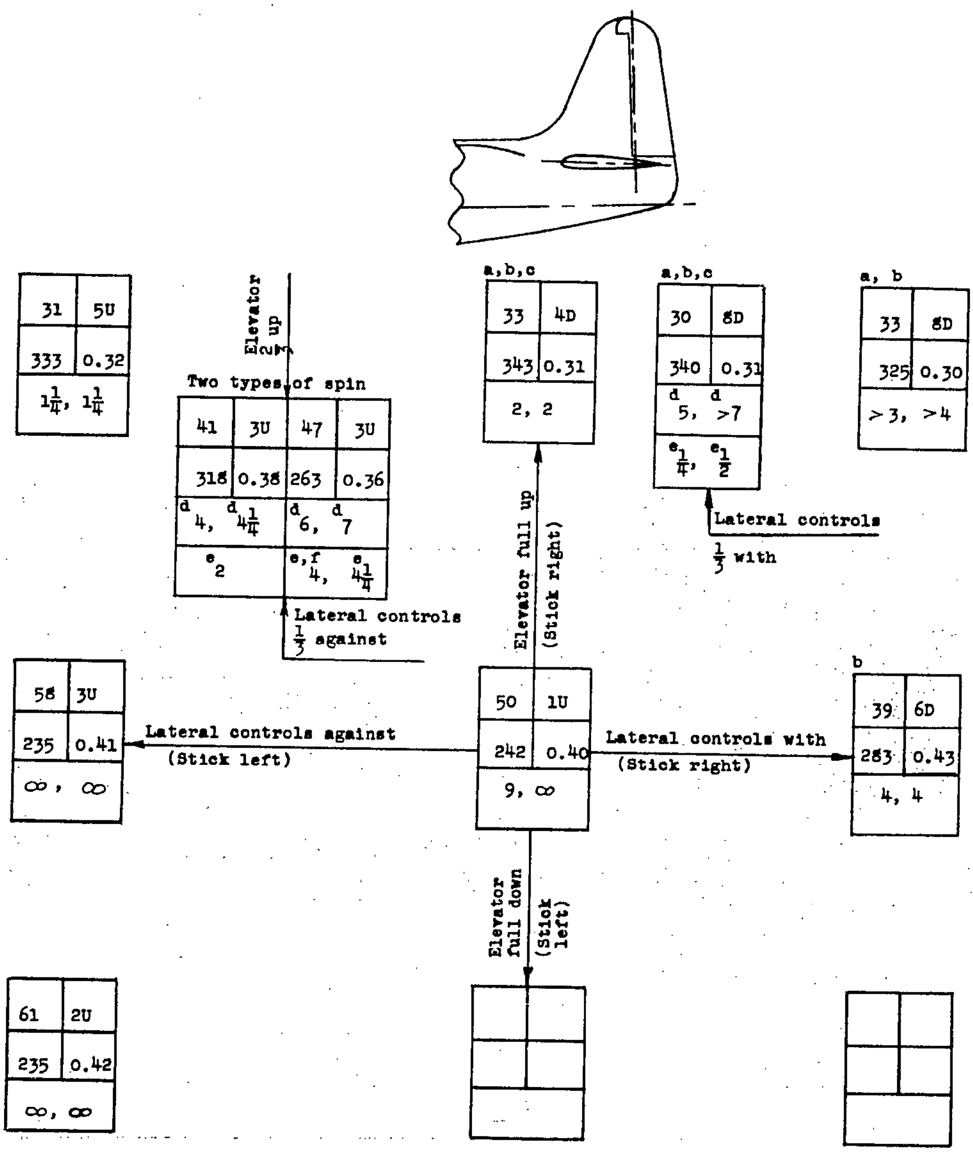
CHART 2.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{24}$-SCALE MODEL OF GRUMMAN AF-2S AIRPLANE EQUIPPED WITH ORIGINAL TAIL IN CATAPULT LOADING

[Loading point 2 in table II and fig. 11; flaps neutral; cockpit closed; landing gear retracted; slots open; recovery attempted by full rapid rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder full with spins); right erect spins]



[a]Wandering spin.
[b]Whipping spin.
[c]Oscillates in pitch, range or average value given.
[d]Recovery attempted by reversing rudder from full with to $\frac{2}{3}$ against the spin.
[e]Recovery attempted by simultaneous reversal of the rudder from full with to $\frac{2}{3}$ against the spin and movement of the elevator from up to $\frac{2}{3}$ down.
[f]Visual estimate.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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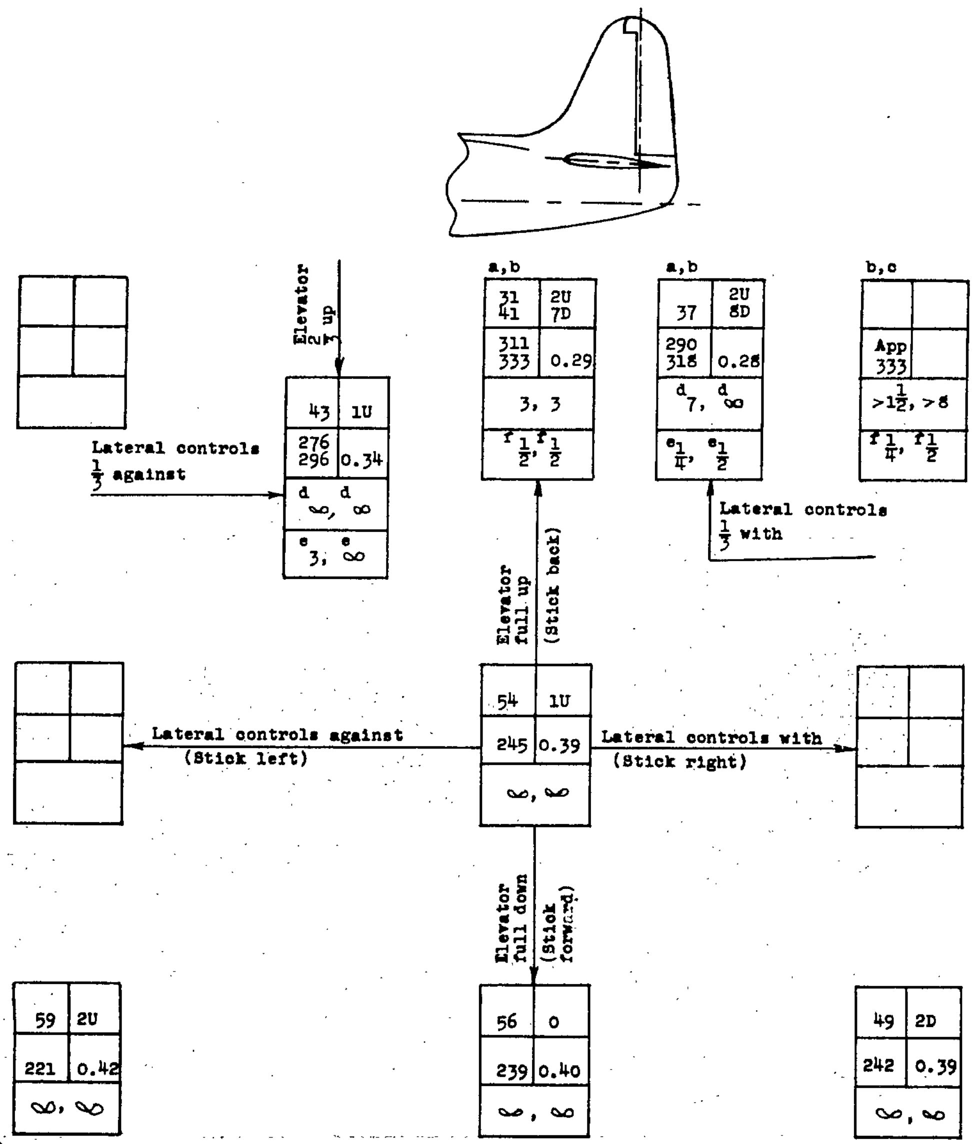
[redacted]

CHART 3.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{24}$-SCALE MODEL OF GRUMMAN AF-2W AIRPLANE

EQUIPPED WITH ORIGINAL TAIL IN MAXIMUM OVERLOAD GROSS WEIGHT LOADING

[Loading point 3 in table II and fig. 11; flaps neutral; cockpit closed; landing gear retracted; slots open; recovery attempted by full rapid rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder full with spins); right erect spins]



[a] Oscillatory in pitch, range of values given.

[b] Wandering spin.

[c] Whipping spin.

[d] Recovery attempted by reversing rudder from full with to $\frac{2}{3}$ against the spin.

[e] Recovery attempted by simultaneous reversal of rudder from full with to $\frac{2}{3}$ against the spin and movement of the elevator from up to $\frac{2}{3}$ down.

[f] Recovery attempted by simultaneous full reversal of rudder and elevator.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

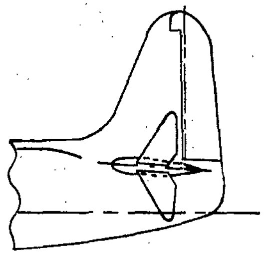
α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

[redacted]

CHART 4.- SPIN AND RECOVERY CHARACTERISTICS OF $\frac{1}{24}$-SCALE MODEL OF GRUMMAN AF-2S, -2W AIRPLANE

EQUIPPED WITH ORIGINAL TAIL WITH TRIANGULAR DUAL FINS INSTALLED ON HORIZONTAL TAIL

[Loading as indicated; cockpit closed; landing gear retracted; slots open; recovery attempted by full rapid rudder reversal unless otherwise indicated (recovery attempted from, and steady-spin data presented for, rudder full with spins); right erect spins]



Loading point 1 on table II and figure 11

Lateral controls $\frac{1}{3}$ against; Elevator $\frac{2}{3}$ up

51	2U
242	0.32
[a] 6, [a] >6	
[b] ∞, [b] ∞	

Loading point 2 on table II and figure 11

Lateral controls $\frac{1}{3}$ against; Elevator $\frac{2}{3}$ up

52	1U
269	0.36
[b] 5, [b] ∞	

Loading point 3 on table II and figure 10

Lateral controls

$\frac{1}{3}$ against [c]; Elevator $\frac{2}{3}$ up

35 51	4U 1D
263 296	0.35
[b] 3, [b] $3\frac{1}{4}$	

Neutral [c]; Elevator full up

35 43	0 6D
290 318	0.30
[e] $\frac{1}{4}$, [e] $\frac{1}{2}$	

$\frac{1}{3}$ with [c]; Elevator full up

34 44	0 11D
290 311	0.29
[b] 1, [b] $1\frac{1}{4}$	

Full with [c,d]; Elevator full up

32 46	0 18D
283 304	0.30
[e] $\frac{3}{4}$, [e] 1	

[a]Recovery attempted by reversing rudder from full with the spin to $\frac{2}{3}$ against the spin.
[b]Recovery attempted by simultaneous reversal of the rudder from full with the spin to $\frac{2}{3}$ against the spin and movement of the elevator from up to $\frac{2}{3}$ down.
[c]Oscillatory spin. Range of values given.
[d]Wandering spin.
[e]Recovery attempted by simultaneous reversal of the rudder from full with the spin to full against the spin and movement of the elevator from full up to full down.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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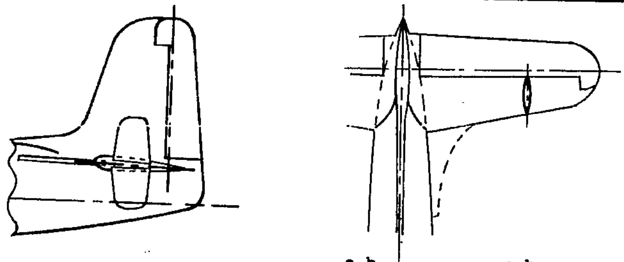
CHART 5.- SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{24}$-SCALE MODEL OF GRUMMAN AF-2W AIRPLANE IN BASIC FLIGHT LOADING LESS WING FUEL - REVISED TAIL AND LARGE ANTISPIN FILLETS INSTALLED (MODIFICATION 4 IN FIG. 4)

[Loading point 4 in table II and fig. 11; flaps neutral; cockpit closed; landing gear retracted; slots open; recovery attempted by full rapid rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder full with spins); right erect spins]



a

App 296	
$\frac{3}{4}$, $1\frac{1}{2}$	
c$\frac{1}{4}$, c$\frac{1}{4}$	

Elevator $\frac{2}{3}$ up; Lateral controls $\frac{1}{3}$ against

39	1D
272	0.32
d ∞, d ∞	
e 2, e 2	

a,b

App 296	
>3, >4	
c$\frac{1}{4}$, c$\frac{1}{4}$	

a,b

296	
d >2, d >3	
e$\frac{1}{4}$, e$\frac{1}{4}$	

Lateral controls $\frac{1}{3}$ with

a,b

App 296	
>$1\frac{1}{2}$, >2	
c$\frac{1}{2}$, c$\frac{1}{2}$	

Elevator full up (Stick back)

Lateral controls against (Stick left)

46	4U
242	0.36
∞, ∞	

Lateral controls with (Stick right)

Elevator full down (Stick forward)

49	5U
228	0.37
∞, ∞	

No	spin

[a]Wandering spin.
[b]Whipping spin.
[c]Recovery attempted by simultaneous reversal of the rudder from full with to full against the spin and of the elevator from full up to full down.
[d]Recovery attempted by reversal of the rudder from full with to $\frac{2}{3}$ against the spin.
[e]Recovery attempted by simultaneous reversal of the rudder from full with to $\frac{2}{3}$ against and of the elevator from up to $\frac{2}{3}$ down.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	ϕ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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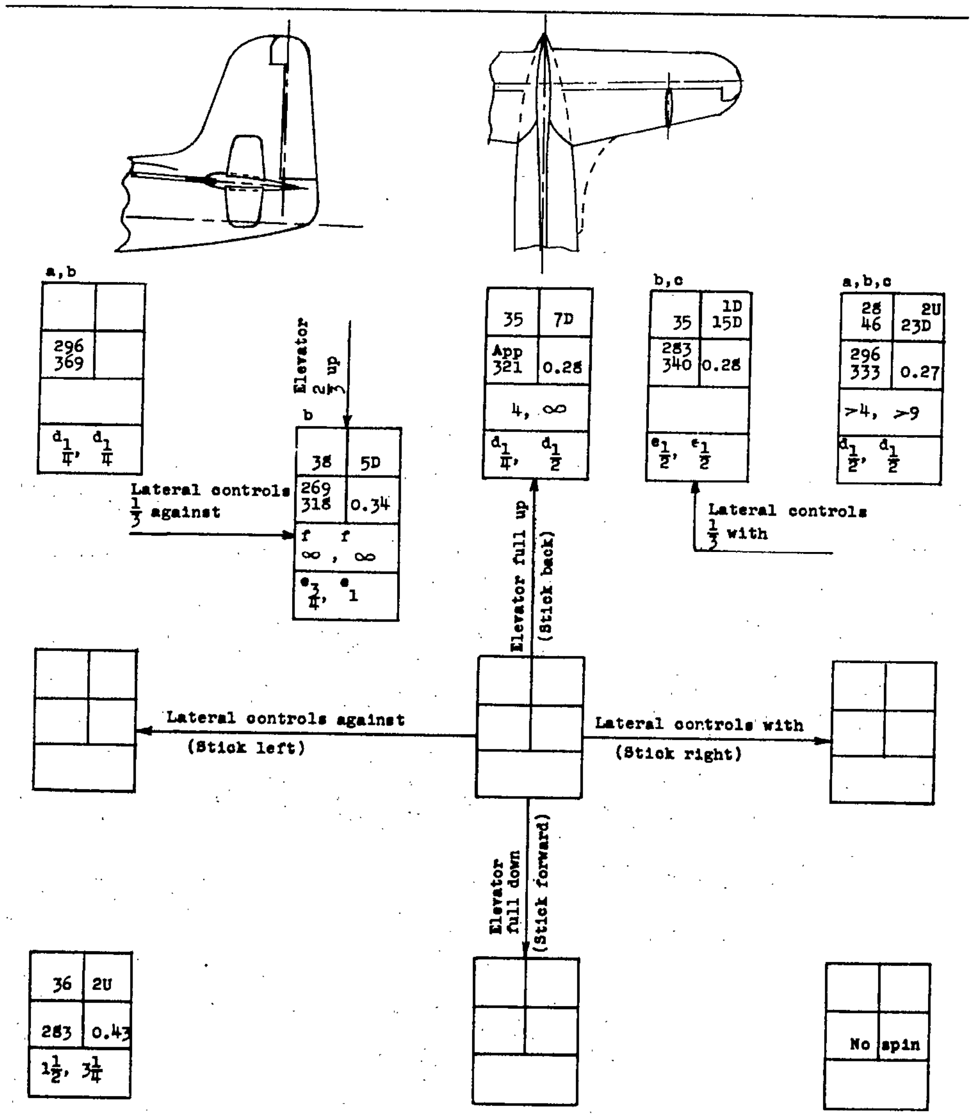
[redacted]

CHART 6.- SPIN AND RECOVERY CHARACTERISTICS FOR A $\frac{1}{24}$-SCALE MODEL OF GRUMMAN AF-2W AIRPLANE IN MAXIMUM OVERLOAD GROSS WEIGHT LOADING - REVISED TAIL AND LARGE ANTISPIN FILLETS INSTALLED (MODIFICATION 4 IN FIG. 4)

[Loading point 3 in table II and fig. 11; flaps neutral; cockpit closed; landing gear retracted; slots open; recovery attempted by full rapid rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder full with spins); right erect spins]



[a]Wandering spin.
[b]Oscillatory in pitch.
[c]Whipping spin.
[d]Recovery attempted by simultaneous reversal of the rudder from full with to full against the spin and of the elevator from full up to full down.
[e]Recovery attempted by simultaneous reversal of the rudder from full with to $\frac{2}{3}$ against the spin and of the elevator from up to $\frac{2}{3}$ down.
[f]Recovery attempted by reversal of the rudder from full with to $\frac{2}{3}$ against the spin.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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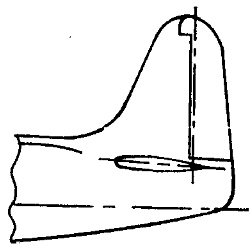
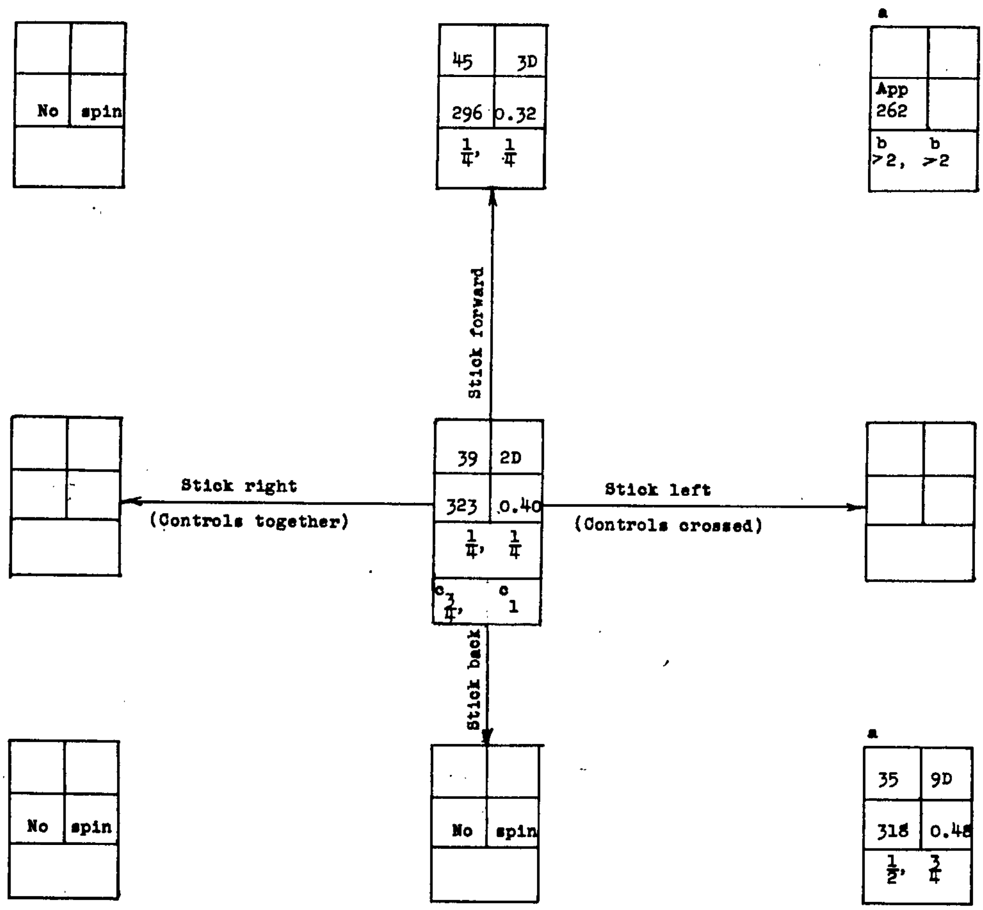
[redacted]

[redacted]

CHART 7.- INVERTED SPIN AND RECOVERY CHARACTERISTICS OF A $\frac{1}{24}$ - SCALE MODEL OF GRUMMAN AF-2S AIRPLANE EQUIPPED WITH ORIGINAL TAIL IN BASIC LOADING

[Loading point 1 in table II and fig. 11; flaps neutral; cockpit closed; landing gear retracted; slots open; recovery attempted by full rapid rudder reversal except as noted (recovery attempted from, and steady-spin data presented for, rudder full with spins); right erect spins]





[a]Violent oscillatory and whipping spin.
[b]Visual estimate.
[c]Recovery attempted by neutralization of the rudder.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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[redacted]

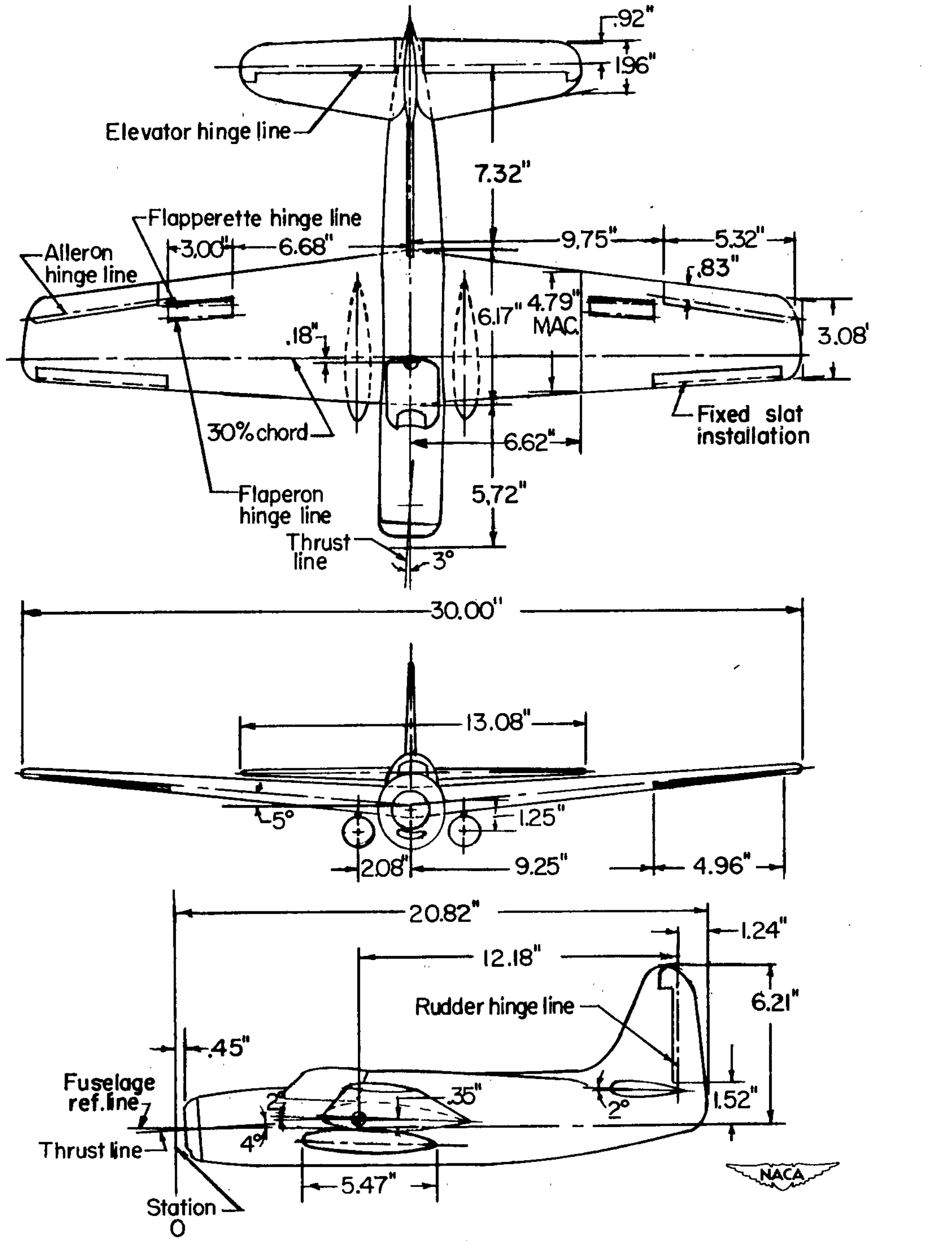

Figure 1.- Three-view drawing of the $\frac{1}{24}$-scale model of the Grumman AF-2S airplane equipped with the original tail as tested in the Langley 20-foot free-spinning tunnel. Center of gravity is shown for the basic flight loading. Aileron and flaperon dimensions are given in the wing-chord plane.

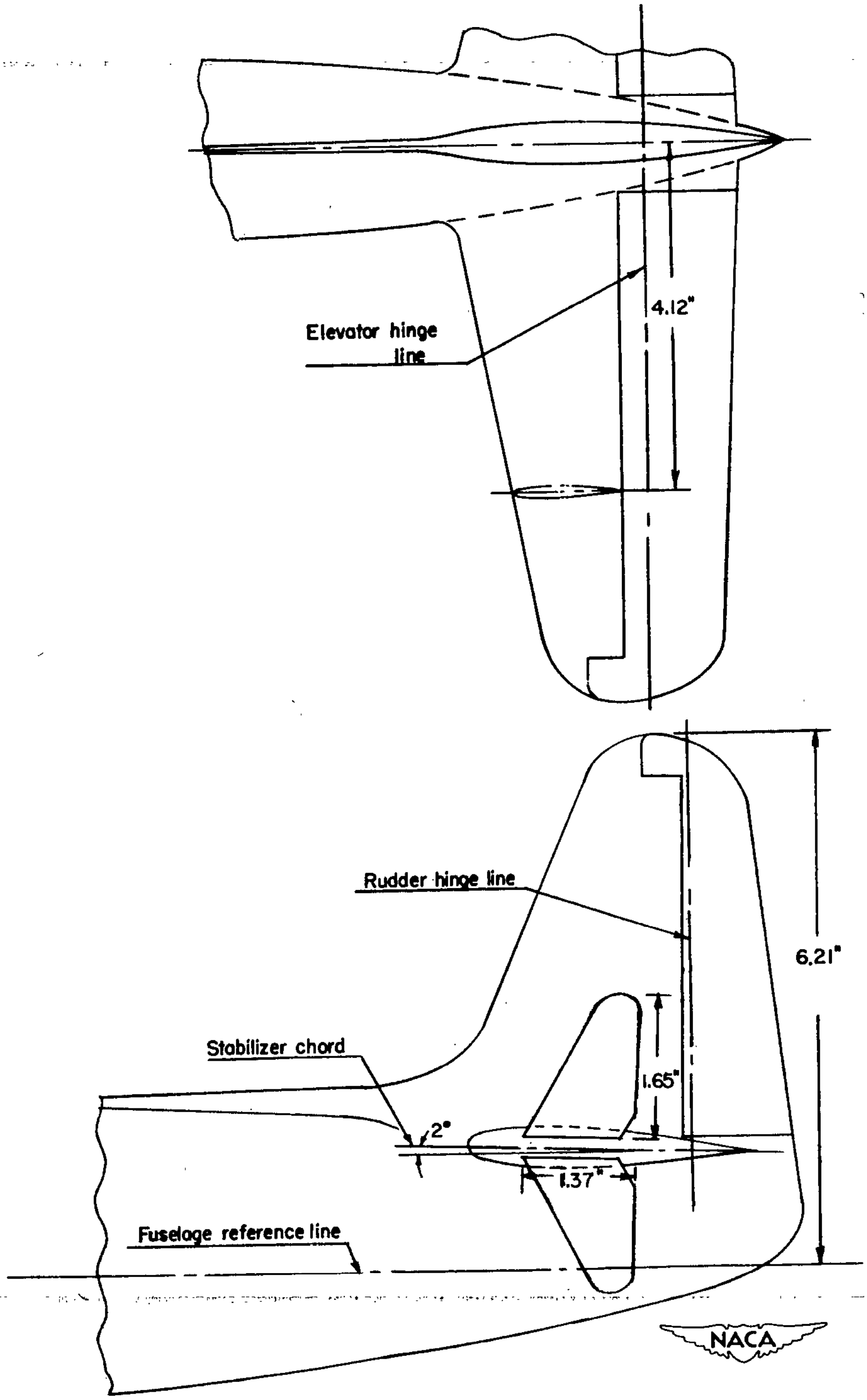

Figure 2.- Original tail of the $\frac{1}{24}$-scale model of the Grumman AF-2S, -2W airplane with the triangular dual fins installed.

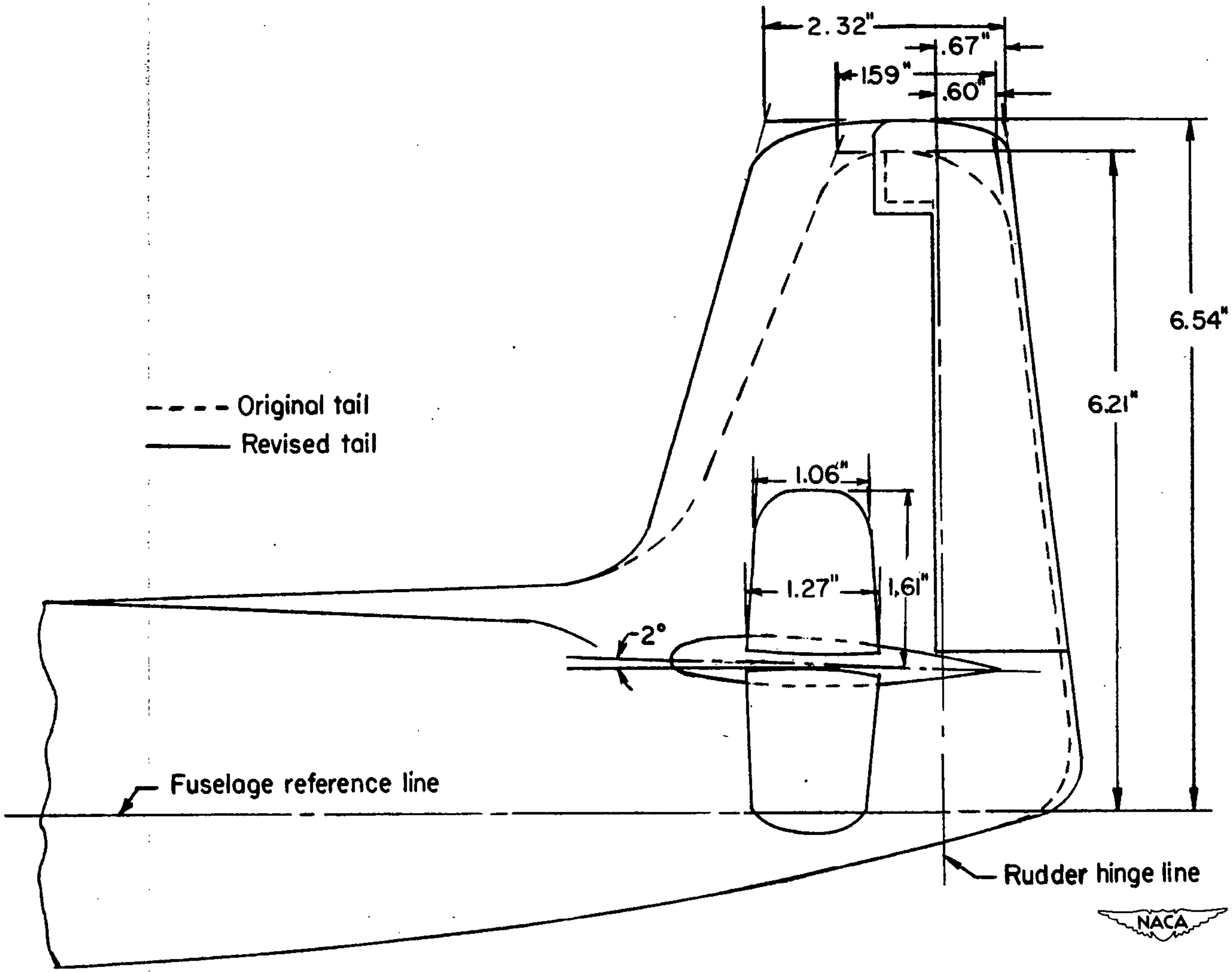

Figure 3.- Comparison drawing of the original and revised tail of the $\frac{1}{24}$-scale model of the Grumman AF-2S, -2W airplane as tested in the Langley 20-foot free-spinning tunnel.

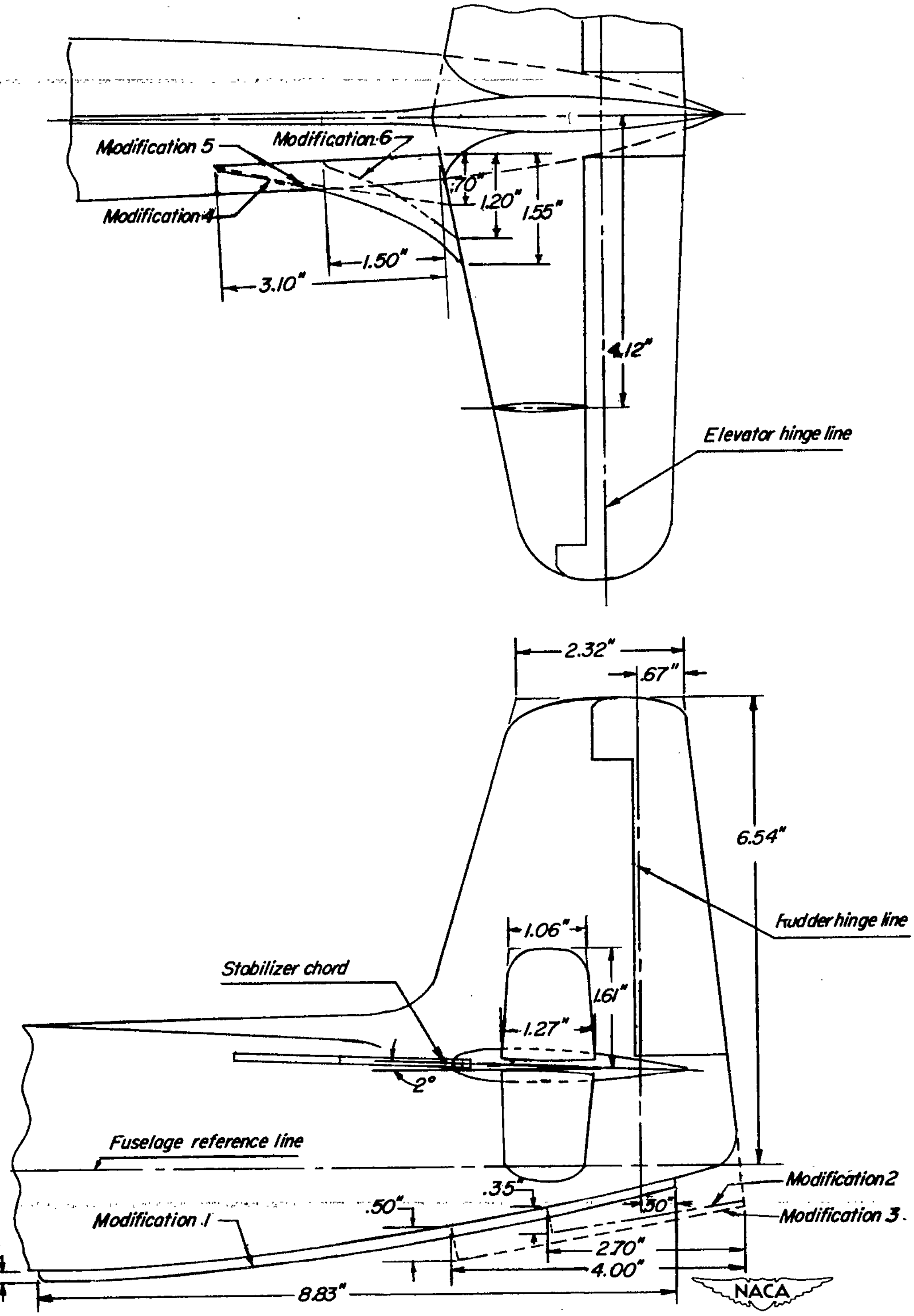

Figure 4.- Revised tail configuration and various modifications tested on the $\frac{1}{24}$-scale model of the Grumman AF-2S, -2W airplane.

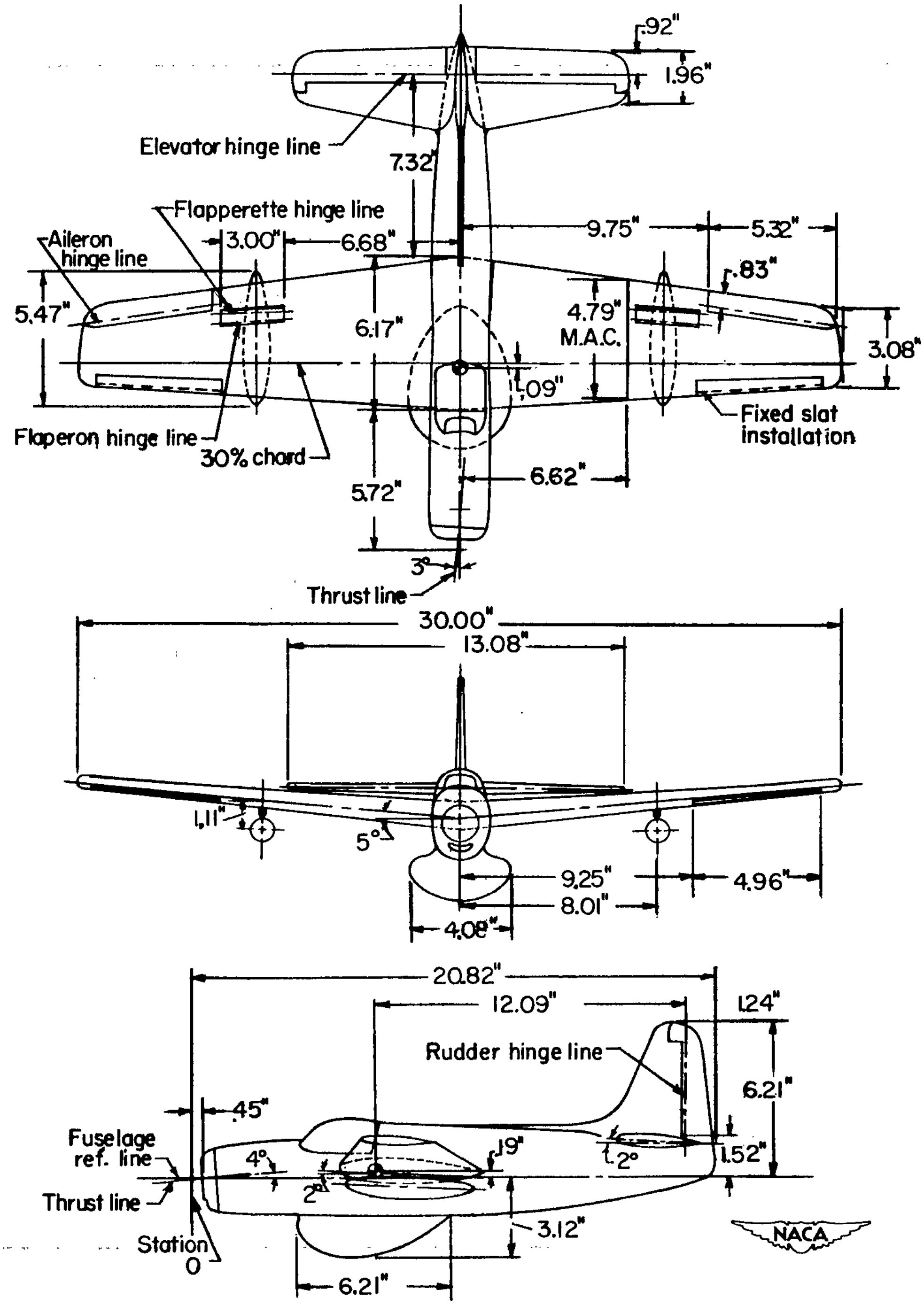

Figure 5.- Three-view drawing of the $\frac{1}{24}$-scale model of the Grumman AF-2W airplane equipped with the original tail as tested in the Langley 20-foot free-spinning tunnel. Center of gravity is shown for the maximum overload gross weight loading. Aileron and flaperon dimensions are given in the wing-chord plane.

[redacted]

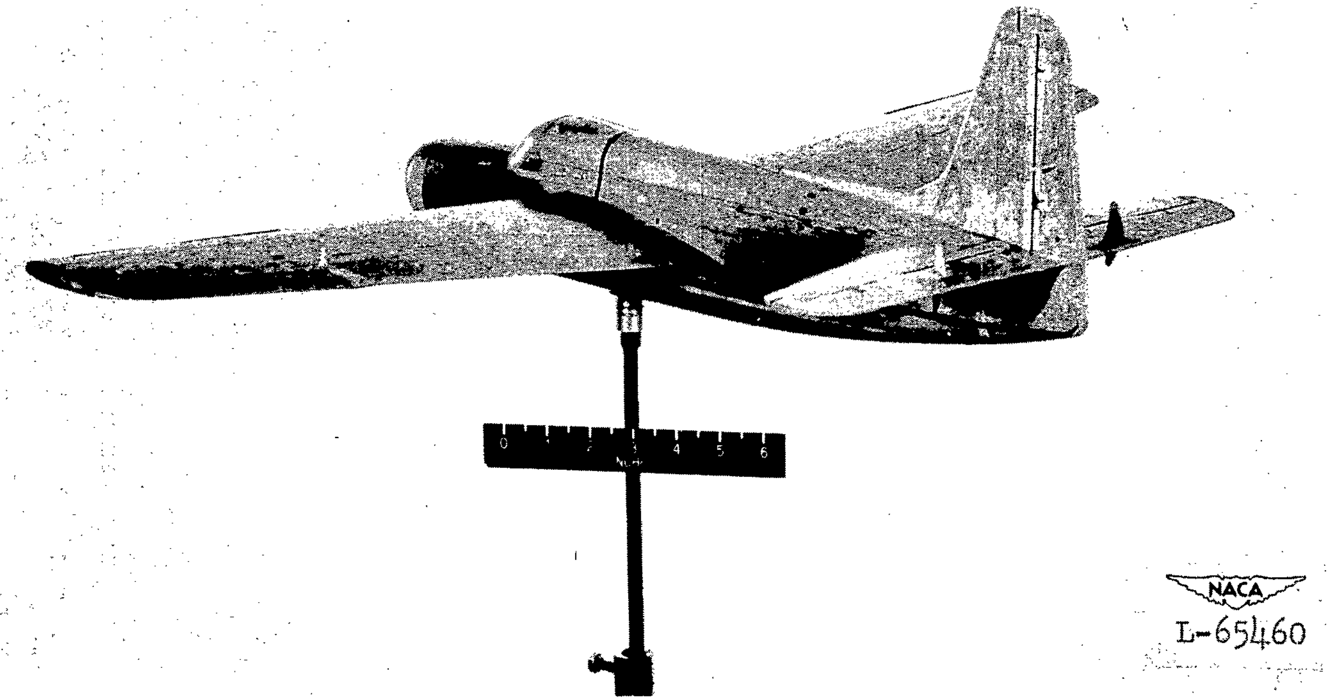

Figure 6.- Photograph of the $\frac{1}{24}$ - scale model of the Grumman AF-2S airplane equipped with the original tail.

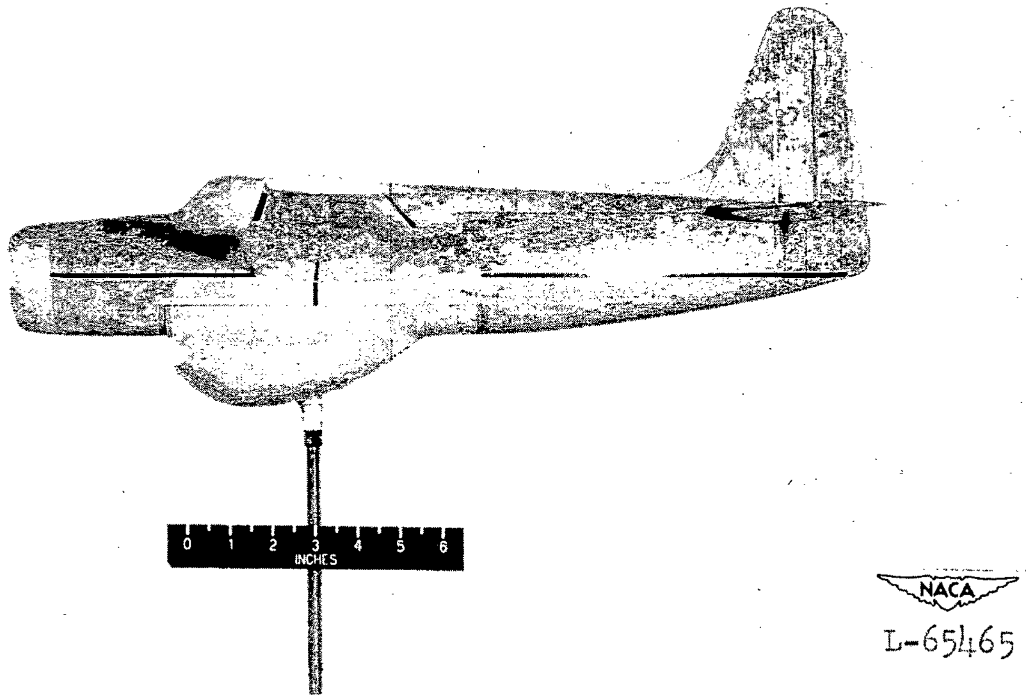

Figure 7.- Photograph of the $\frac{1}{24}$-scale model of the Grumman AF-2W airplane equipped with the original tail.

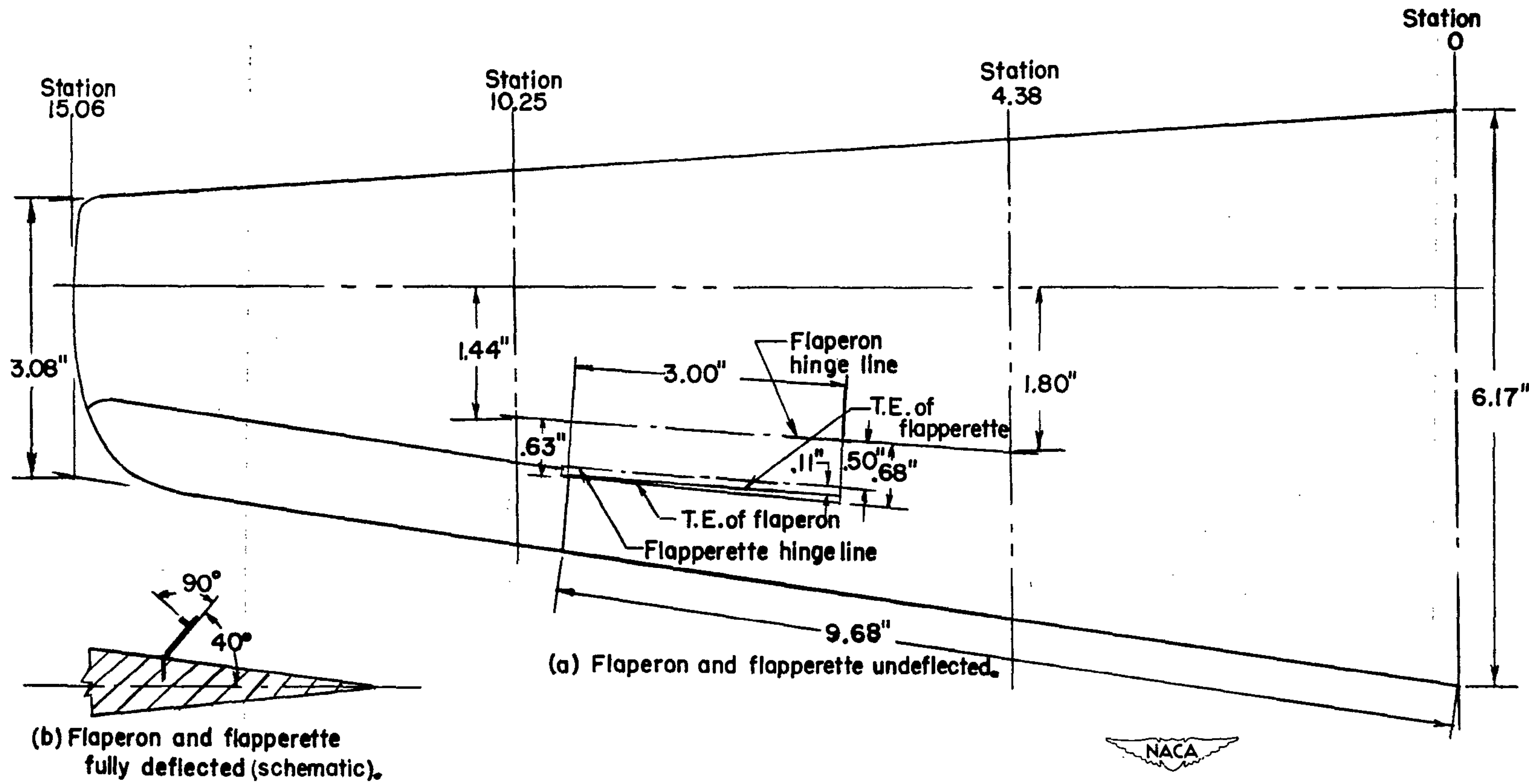

Figure 8.- The geometry of the flaperon and flapperette investigated on the $\frac{1}{24}$-scale model of the Grumman AF-2S, -2W airplane.

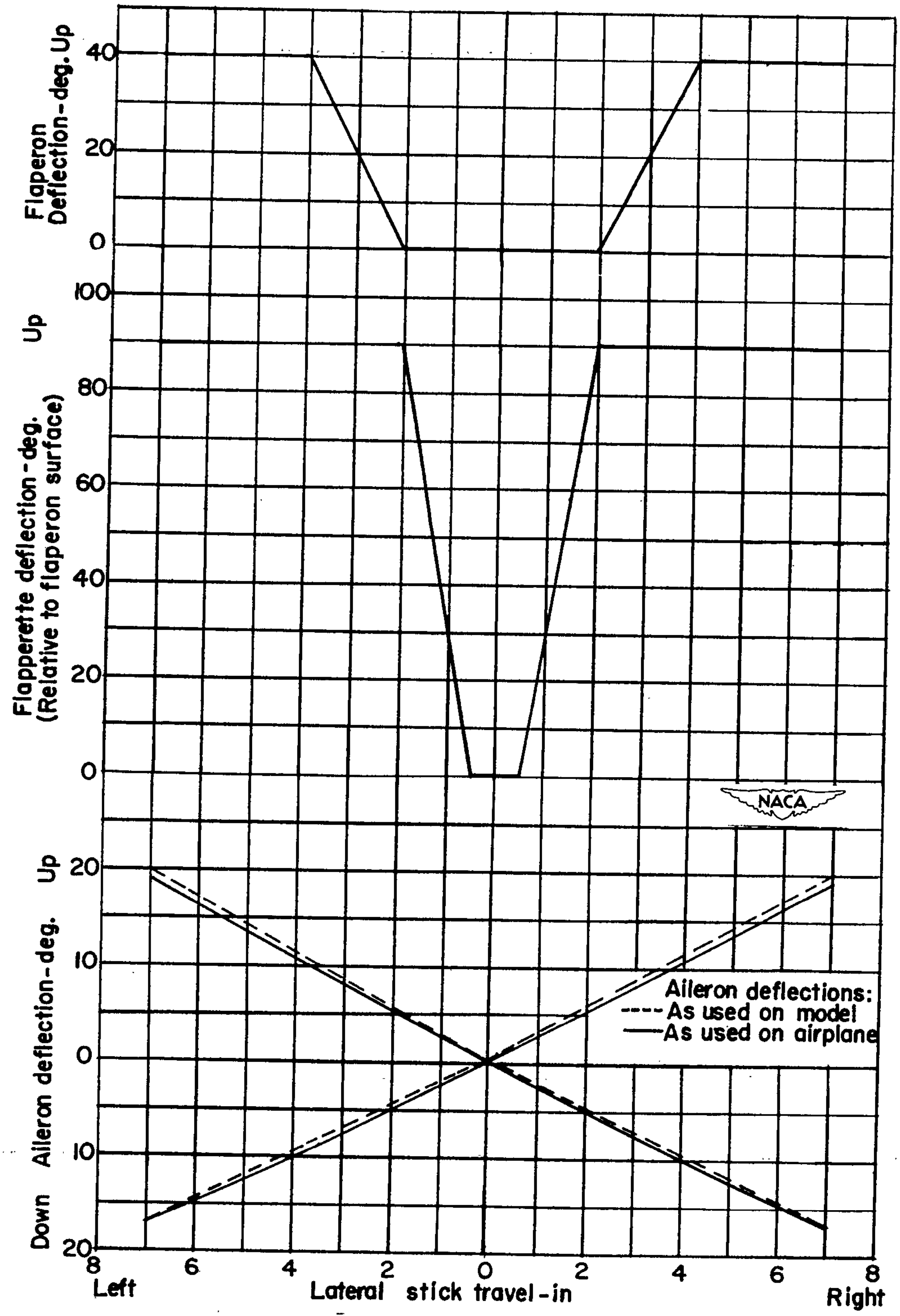

Figure 9.- Lateral-control deflections with stick displacement of the Grumman AF-2S, -2W airplane.

Figure 10.- Photograph of the $\frac{1}{24}$-scale model of the Grumman AF-2S airplane equipped with the original tail spinning in the Langley 20-foot free-spinning tunnel.

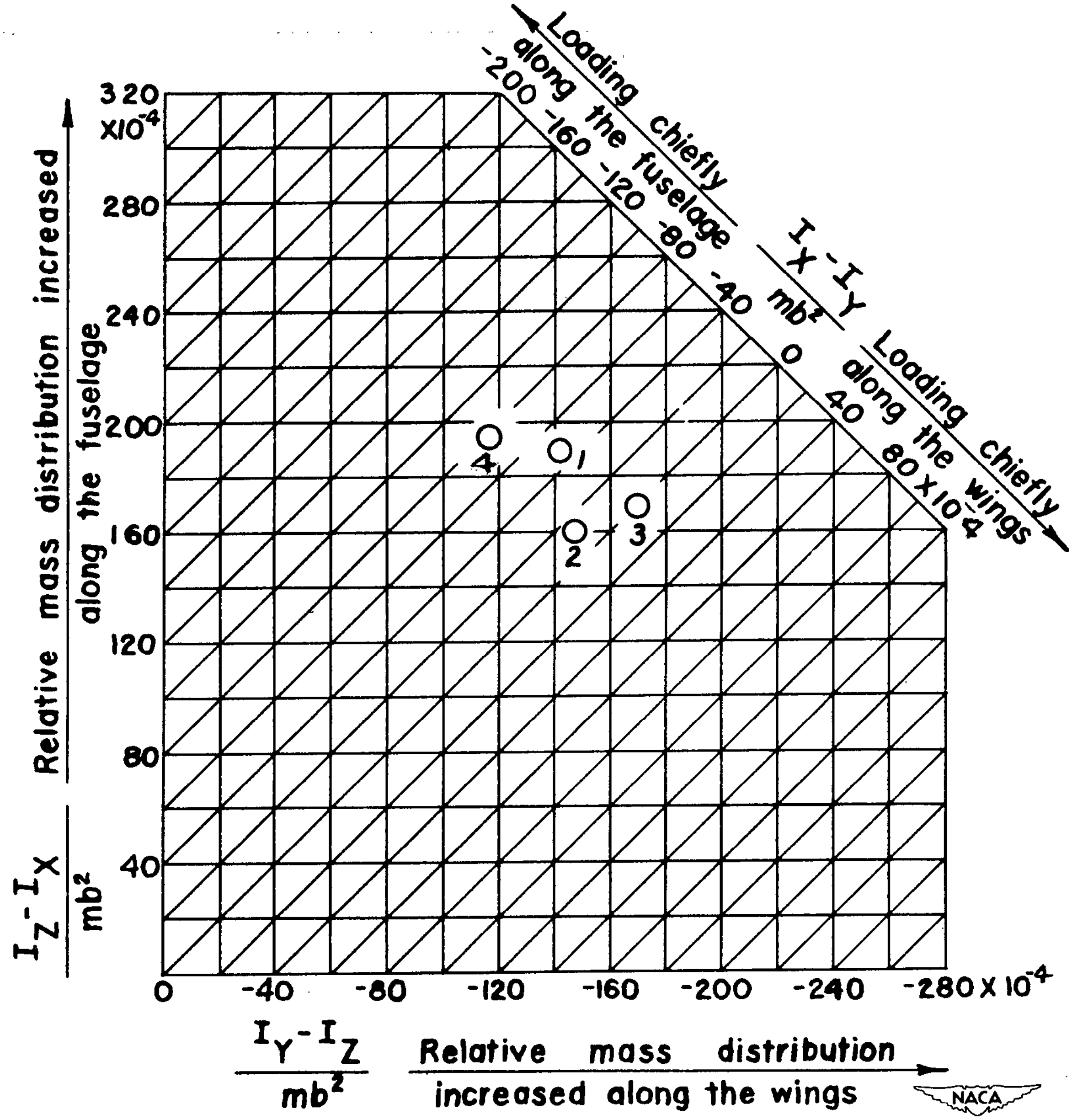

Figure 11.- Mass parameters for the loading conditions of the Grumman AF-2S, -2W airplane tested on the $\frac{1}{24}$-scale model. (Points are for loadings listed in table II.)